Géographie physique et Quaternaire

Ice Sheets and Ice Streams: Thoughts on the Cordilleran Ice Sheet Symposium
Inlandsis et courants glaciaires : réflexions inspirées du symposium sur l'Inlandsis de la Cordillère

William H. Mathews

Volume 45, numéro 3, 1991

L'Inlandis de la Cordillère
The Cordilleran Ice Sheet

URI : https://id.erudit.org/iderudit/032873ar
DOI : https://doi.org/10.7202/032873ar

Aller au sommaire du numéro

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Découvrir la revue

Citer cet article

Mathews, W. H. (1991). Ice Sheets and Ice Streams: Thoughts on the Cordilleran Ice Sheet Symposium. *Géographie physique et Quaternaire*, *45*(3), 263–267. https://doi.org/10.7202/032873ar

Résumé de l'article

On discute ici de préconceptions sur la signification des termes « Inlandsis de la Cordillère » et « courant glaciaire ». On décrit d'abord les courants glaciaires contemporains de l'Antarctique. On désigne ensuite le chenal laurentien et les dépressions qui traversent le plateau continental entre Vancouver et l'archipel de la Reine-Charlotte comme des endroits susceptibles d'avoir été, dans le passé, la voie de courants glaciaires.

Géographie physique et Quaternaire, 1991, vol. 45, n° 3, p. 263-267, 4 fig.

ICE SHEETS AND ICE STREAMS: THOUGHTS ON THE CORDILLERAN ICE SHEET SYMPOSIUM

William H. MATHEWS, Department of Geological Sciences, University of British Columbia, Vancouver, British Columbia V6T 1W5.

ABSTRACT This paper comments on preconceptions about what is meant by the terms "Cordilleran Ice Sheet" and "ice stream". Contemporary Antarctic ice streams are described. The Laurentian Channel and throughs crossing the continental ice shelf between Vancouver and Queens Charlotte Islands are suggested as candidates for the tracks of past ice streams.

RÉSUMÉ *Inlandsis et courants glaciaires: réflexions inspirées du symposium sur l'Inlandsis de la Cordillère.* On discute ici de préconceptions sur la signification des termes «Inlandsis de la Cordillère» et «courant glaciaire». On décrit d'abord les courants glaciaires contemporains de l'Antarctique. On désigne ensuite le chenal laurentien et les dépressions qui traversent le plateau continental entre Vancouver et l'archipel de la Reine-Charlotte comme des endroits susceptibles d'avoir été, dans le passé, la voie de courants glaciaires.

INTRODUCTION

The oral presentations at the Cordilleran Ice Sheet symposium began, appropriately, with Jackson and Clague's paper dealing with history of thought on the ice sheet from the time of G.M. Dawson. In Jackson's words, Dawson arrived in western Canada in 1875 "carrying handbaggage of preconceptions," (attributing for example to floating ice evidence we now know as marks of glaciation) and left in 1894 with a much more sophisticated view. Jackson's opening remarks about the handbaggage of preconceptions struck me as being a particularly apt theme to pursue, as preconceptions persist with respect to the Cordilleran Ice Sheet and the nature of ice flow within it.

I do not automatically deplore preconceived notions provided that they do not become so deeply carved in stone that they cannot be erased if necessary; indeed some preconception is essential for efficient communication. It would be terribly trying if every author had to specify what he means by the term 'glacier' or had to defend its ability to erode bedrock (even though we can accept its ability to override soils, outwash, and lake beds without always removing them). Nevertheless I detected some concepts still fuzzy enough in the minds of the participants (speakers as well as audience) to cause some confusion. My purpose in writing this paper is to comment on two topics that are important to our perception of Cordilleran glaciation.

WHAT IS MEANT BY CORDILLERAN ICE SHEET?

The use of the term "Cordilleran Ice Sheet" proved to be problematic and inconsistent among symposium participants. Does this entity include, or should it include, the ice on Queen Charlotte Islands, on Vancouver Island, or in the northern Rocky Mountains, or is the term "Cordilleran Glacier Complex" more appropriate. This problem is not unique to the Cordillera; the Antarctic Ice Sheet offers the same dilemma. Should, for example, the ice of Western Antarctica, with its independent flow pattern be included as part of the Antarctic Ice Sheet? Could we consider the Cordillera as supporting a glacier complex during early stages of glaciation, but once the isolated ice masses coalesced and particularly when an ice dome developed over the Interior Plateaus should it not qualify as a full fledged ice sheet?

WERE THERE ICE STREAMS IN THE CORDILLERAN ICE SHEET?

The convenience of using a single word or phrase to convey a complex behaviour or characteristic carries with it a hazard of being ambiguous and hence of being misunderstood. An example drawn from the oral presentations at the Cordilleran Ice Sheet symposium lies in the currently fashionable term "ice stream".

Inferred past ice streams were associated with loci of anomalously deep erosion, for example the Okanagan Valley in southern British Columbia, and sites of greatest flux, where networks of glaciers moved through valleys and crossed ridges at their low points, for example in the southern Coast Mountains. Comparisons were made between these ice streams and Antarctic examples, particularly ice streams feeding the Ross Ice Shelf (Fig. 1). Certain implicit assumptions are involved in such comparisons: (1) an ice stream is, indeed, capable of abnormally rapid erosion; (2) it persists for a sufficiently long time, or recurs repeatedly at the same site; and (3) the scale of such valleys as the Okanagan bears a relationship to the scale of the inferred ice stream. Are these valid assumptions in light of our knowledge of contemporary ice streams?

Manuscrit reçu le 15 février 1991; manuscrit révisé accepté le 30 septembre 1991

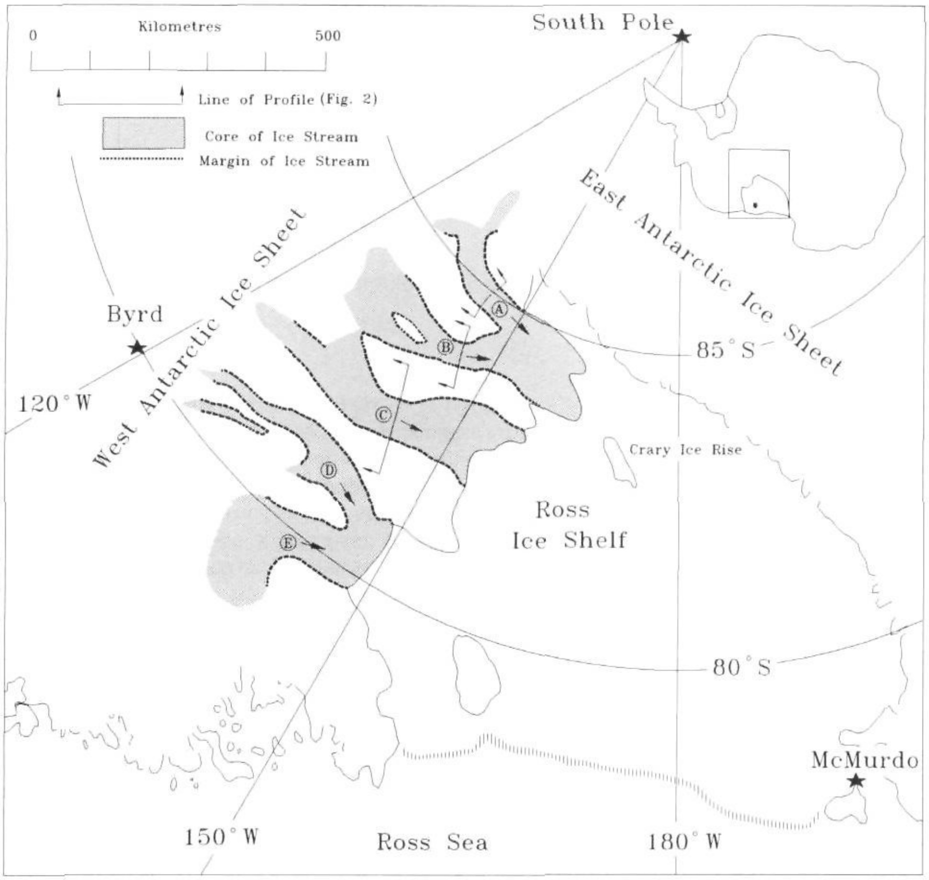

FIGURE 1. Location map of ice streams A to E flowing into Ross Ice Shelf, Antarctica (from Engelhardt *et al.*, 1990, Fig. 1).

Localisation des courants glaciaires A à E qui s'écoulent vers la plate-forme de Ross (de Engelhardt et al., *1990, fig. 1).*

CONTEMPORARY ICE STREAMS

The phrase "ice stream", in the context of Antarctic glaciers, was defined by Charles W. Swithinbank in 1954 (p. 185) as 'part of an inland ice sheet in which the ice flows more rapidly than, and not necessarily in the same direction, as the surrounding ice'. Later Bader (1965, p. 11) in his discussion of the Greenland ice cap wrote 'an ice stream is something akin to a mountain glacier consisting of a broad accumulation basin and a narrower outlet valley glacier; but a mountain glacier is laterally held in by rock slopes while the ice stream is contained by slower moving surrounding ice.' Bentley (1987) pointed out that there is a gradation between ice streams totally confined by more slowly moving ice and outlet glaciers bounded by bedrock on one or both sides. Jacobshavn Glacier in western Greenland, one of Bader's examples of an ice stream, enters the sea in a rock-walled fiord where there is but a narrow strip of relatively slow-moving ice between the ice stream and bedrock. And Ice Stream B, one of several feeding into the head of the Ross Ice Shelf in Antarctica (Fig. 1), lacks a wide accumulation basin but in other respects fits Swithinbank's and Bader's definitions.

How then do we recognize ice streams as defined above? It is in satellite photographs or air-photo mosaics that the first hint is likely to be found. The grand scale of a typical Antarctic ice stream, mostly 15 to 75 km wide, generally prevents inclusion of both margins in a single air photo. The ice stream is bounded on each of its two sides by a band of rough, heavily crevassed ice (Fig. 2) where much of the velocity change is concentrated. Longitudinally striped and fluted ice within the stream may be distinguished from smoother, slow-moving ice outside the gently curving and commonly subparallel lateral boundaries. The more crevassed ice may appear as heavily 'cluttered' in airborne radar profiling (Rose, 1979). Streams may be simple or branched. Some may fork around downstream obstacles. Spacing between streams is comparable to their widths. Longitudinal profiles on the ice surfaces are low. Confirmation of a suspected ice stream by measurement of ice-surface velocities is routine but time-consuming and requires sophisticated equipment. Values obtained generally range from a few hundred metres to a few kilometres per year (Bentley, 1987); ice stream C, though bearing the marks of former fast flow now moves only 5 m per year (Whillans *et al.*, 1987). Other evidence suggests that the limits of an ice stream may shift with time, and this raises the question whether an ice stream, after dying out, can become reactivated at the same site.

Almost all information on the deeper parts of ice streams is obtained by remote sensing, including seismic and radar profiling. Records of both surface and bottom topography is available for several profiles of Ice Streams A, B, and C (Shabtaie *et al.*, 1987) (Fig. 2). These show ice thicknesses reaching 1100 m in stream A and 1850 m in stream B1. They show, too, spots on the bed *below sea level* by as much as 700 m under stream C and 1400 m under streams A and B. Ice streams fill and overflow valleys 30 to 60 km across and 200 to 500 m

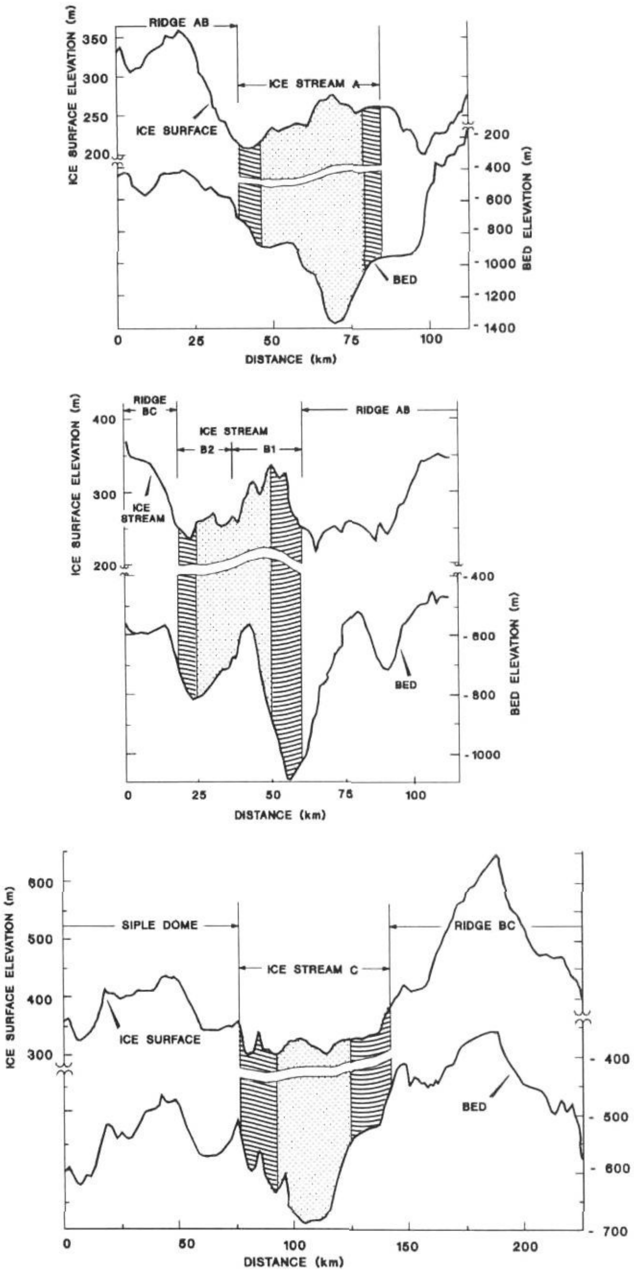

FIGURE 2. Profiles of ice steams A (top), B (middle), and C (bottom). Heavy and light shading represent the marginal shear zones and the less chaotic cores of the ice streams respectively. Note the varying horizontal and vertical scales and vertical exaggerations (redrawn from Shabtaie *et al.*, 1987, Figs. 5, 8, and 9; reproduced with permission of the American Geophysical Union).

Profils des courants glaciaires A (haut), B (centre) et C (bas). La trame foncée représente les zones marginales crevassées et la trame pâle, les parties centrales moins chaotiques. Noter les différences d'échelles et d'exagérations verticales (repris de Shabtaie et al., *1987, fig. 5, 8 et 9; figures reproduites avec la permission de l'American Geophysical Union).*

deep. Valley sides rise, mostly at angles of less than 1° from narrow valley floors. The axis of the ice stream does not necessarily coincide with the centre of the subglacial valley.

Detailed seismic studies along an 8.3 km profile in the upper part of Ice Stream B have indicated that the ice is directly underlain by a layer several metres thick of porous and unfrozen water-saturated sediment, assumed to be a till (Blankenship *et al.*, 1987). This interpretation was confirmed by deep drilling in the austral summers of 1988-89 and 1989-90 (Engelhardt *et al.*, 1990). The high porosity of the till, about 40 %, was considered to be a result of active deformation. Its pore pressure was almost enough to support the load of overlying ice. The till here rests on a bedrock surface with longitudinal flutes hundreds of metres across and 6 to 13 m deep.

RECOGNITION OF PLEISTOCENE ICE STREAMS

With so little known about the conditions and processes operating at the bed of contemporary ice streams, it seems doubtful that the site of an ancient ice stream can be identified solely from a track engraved on the substratum. It will remain a challenge until more is learned about the subglacial topography of the Greenland and Antarctic ice sheets and the erosional prorcesses under both the slow and the fast-moving ice.

Nothwithstanding these problems, there are features in Canada, on the same scale as Antarctic ice streams, that might be considered tracks of former ice streams. One such feature lies in the southwestern Canadian Cordillera, on the continental shelf between Vancouver Island and Queen Charlotte Islands (Fig. 3). Here are three broad, but shallow and gently curving troughs described and illustrated in a paper by Luternauer and Murray (1983) and even more graphically represented in two charts by Sawyer (1989). The troughs are 15 to 20 km across, within the limits of the smaller Antarctic ice streams. They are separated from one another by relatively flat-topped 'banks' which are little wider than the troughs themselves. Depths of the trough floors below their rims range from about 100 to 200 m. Most troughs head on the inner continental shelf but at least one is linked to a much narrower and deeper fiord within the Coast Mountains (Fig. 4). They extend southwest to the brink of the continental slope where they terminate abruptly at the heads of a series of submarine canyons. Air-gun profiles of trough floors, walls, and intertrough banks indicate flat to gently-dipping sediments overlying crystalline bedrock, but apart from suggesting an aggradational origin for the outer banks they convey little information on relationships between sediments and glaciation. Thus though the configuration of the troughs resembles the surface outline of an ice stream, we still lack convincing proof of an ice-steam origin.

Farther afield, in eastern Canadian coastral waters, is a spectacular channel 75 km wide, and as much as 400 m deep, extending southeast from the St. Lawrence estuary for 1000 km to the mouth of Cabot Strait and the brink of the Atlantic continental shelf (Fig. 5). Could this be the track of a Pleistocene outlet glacier or ice stream? If so, when was it developed or last occupied?

The large lobate moraines of the southern margin of the Laurentide Ice Sheet — for example the Des Moines Lobe, the Lake Michigan Lobe, and their neighbours — may enclose another possible type of ice-stream track. These lobes have dimensions similar to those of the Antarctic ice streams, the

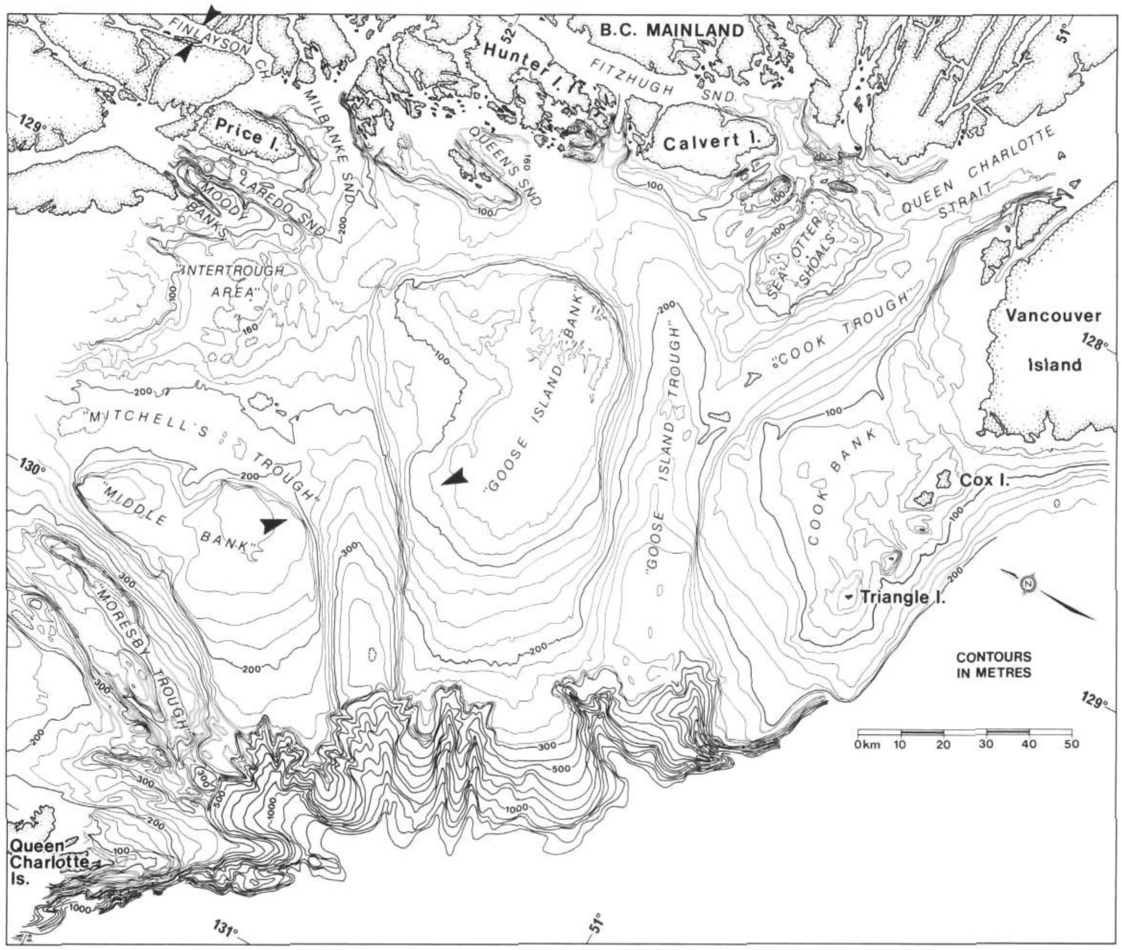

FIGURE 3. Bathymetric map of Queen Charlotte Sound, central British Columbian continental shelf. Arrowheads indicate locations of bathymetric profiles in Figure 4 (from Luternauer and Murray, 1983, Fig., 3; reproduced with permission of the Minister of Supply and Services, Canada, 1991).

Carte bathymétrique du détroit de la Reine-Charlotte, au centre du plateau continental de la Colombie-Britannique. Les flèches donnent l'emplacement des profils bathymétriques de la figure 4 (de Luternauer et Murray, 1983, fig. 3; figure reproduite avec la permission du ministre d'Approvisionnements et Services Canada, 1991).

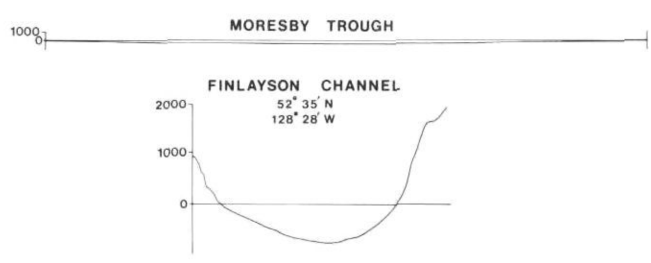

FIGURE 4. True-scale cross-sections of Mitchell's Trough (now Moresby Trough) and Finlayson Channel (vertical scales in metres). Refer to Figure 3 for location (from Luternauer and Murray, 1983, Fig., 3; reproduced with permission of the Minister of Supply and Services, Canada, 1991).

Profils de Mitchell's Trough (maintenant appelé Moresby Trough) et Finlayson Channel (échelles verticales en mètres). La figure 3 donne les emplacements (de Luternauer et Murray, 1983, fig. 3; figure reproduite avec la permission du ministre d'Approvisionnements et Services Canada, 1991).

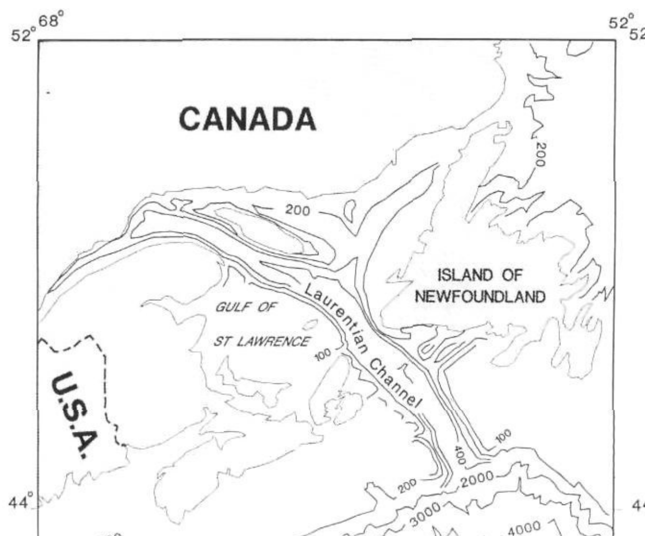

FIGURE 5. Bathymetric chart of the Gulf of St. Lawrence and vicinity showing the Laurentian Channel (generalized from GEBCO, 1978).

Bathymétrie du golfe du Saint-Laurent et des environs montrant le chenal du Saint-Laurent (à partir de GEBCO, 1978).

surface slope of the ice that formed them was evidently low and the pore pressure of the basal water correspondingly high, sufficient almost to float the ice.

Still other candidates for ice-stream tracks may be found within the network of channels between the islands of the Canadian Arctic. Though I doubt if many of these will ultimately qualify, they nevertheless merit investigation with this possibility in mind once the criteria for identifying ice-stream tracks become better established.

CONCLUDING REMARKS

These comments are offered not to develop still more preconceptions, and particularly preconceptions to be held rigidly, but rather to generate a series of multiple working hypotheses as a means of approaching the ultimate answer; the words of St. Paul are appropriate here — "Test all things and hold fast to that which is good".

REFERENCES

Bader, H., 1965. The Greenland Ice Sheet. U.S. Army, Corps of Engineers, Cold Regions Research and Engineering Laboratory, Publication I-B2, 18 p.

Bentley, C.R., 1987. Antarctic ice streams, a review. Journal of Geophysical Research, 92: 8843-8858.

Blankenship, D.D., Bentley, C.R., Rooney, S.T. and Alley, R.B., 1987. Till *beneath Ice Stream B1, properties derived from seismic travel times. Journal* of Geophysical Research, 92: 8903-8912.

Engelhardt, H., Humphrey, N., Kamb, B. and Fahnestock, M., 1990. Physical conditions at the base of a fast moving Antarctic ice stream. Science, 248: 57-58.

GEBCO, 1978. Charts 5-04 and 5-08, scale 1:10,000,000, 5th edition, reprinted 1985. International Hydrographic Organization, published by Canadian Hydrographic Service, Ottawa.

Luternauer, J.L. and Murray, J.W., 1983. Late Quaternary morphologic development and sedimentation, central British Columbia continental shelf. Geological Survey of Canada, Paper 83-21, 38 p.

Rose, K.E., 1979. Characteristics of ice flow in Marie Byrd Land, Antarctica. Journal of Glaciology, 24: 63-75.

Sawyer, B. (*compiler*), 1989. Physiography, Hecate Strait and Queen Charlotte Sound. Canadian Hydrographic Service, Charts 3-1989 and 5-1989.

Shabtaie, S., Whillans, I.M. and Bentley, C.R., 1987. The morphology of Ice Streams A, B, and C. West Antarctica, and their environs. Journal of Geophysical Research, 92: 8865-8884.

Swithinbank, C.W.M., 1954. Ice streams. Polar Record, 7: 185-186.

Whillans, I.M., Bolzan, J. and Shabtaie, S., 1987. Velocity of Ice Streams B and C. Antarctica. Journal of Geophysical Research, 92: 8895-8902.